Analyzing soil parameters to enhance tree growth and design plans for created wetlands in the Piedmont Province

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Introduction

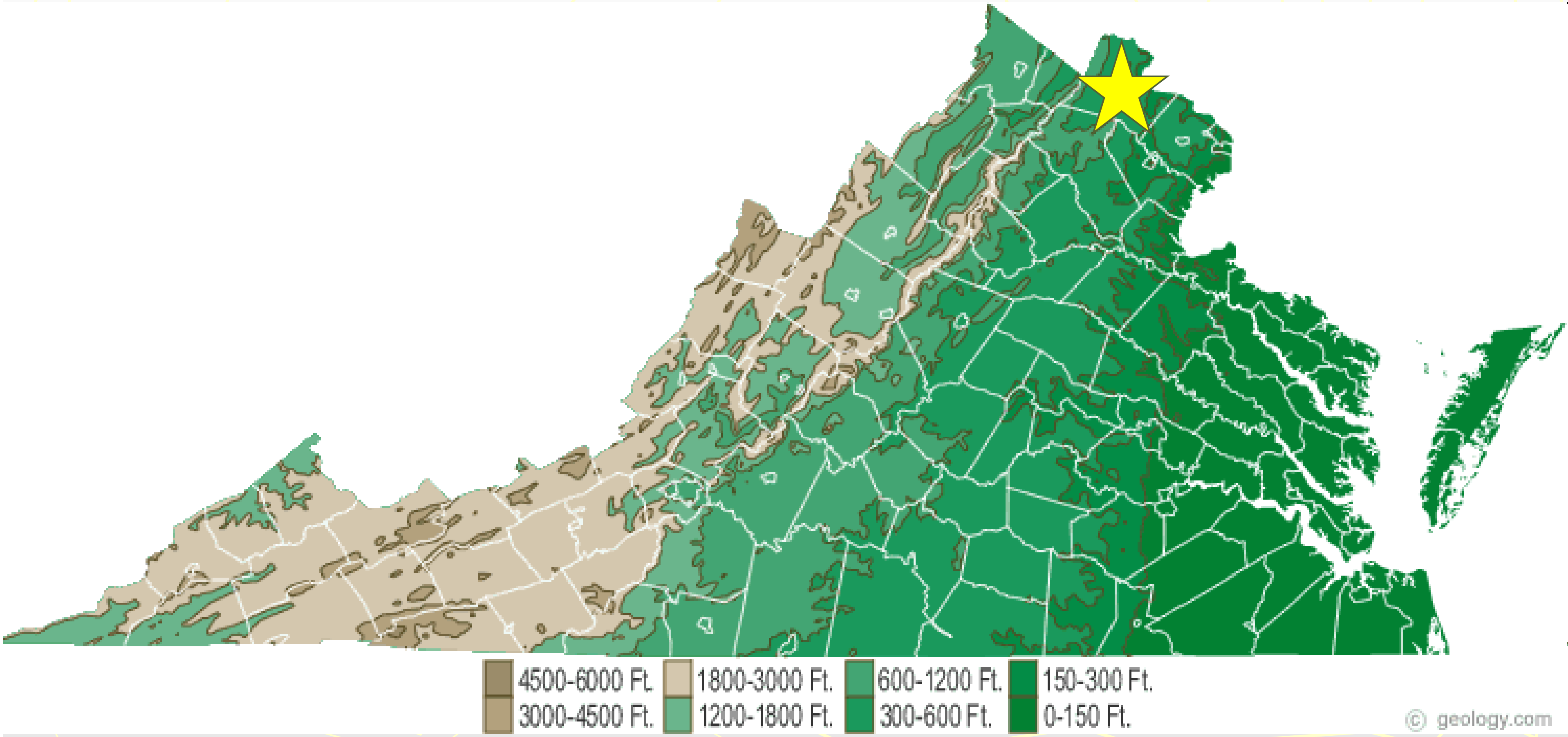
- Forested headwater wetlands termed bottomland forest and wet flats (Braun 1950).
  - Occur alongside low-order streams with predictable flooding over winter with sporadic flooding in summer (Welsch et al. 1995)
  - Willows, ashes, oaks, maples, gums (Cowardin et al. 1979), so tree establishment is a key step in compensation.
- Purpose: Connection to ongoing research
  - Reference Jim Perry's earlier presentation, our sites represent field validation of that large scale experiment.
  - Are soils important for growth at our sites?

Image: Virginia DCR

Two goals for this talk

- Field validation
  - Part of a 7-year study with VIMS
- Soils as a predictor of tree growth
  - Shorter-term study performed in year 3
  - Model the effect of soil parameters on growth of 7 species and 3 stock types.
  - Help inform tree planting strategies in Piedmont created wetlands.

Site Descriptions:
Piedmont Province, Loudoun County Wetland and Stream Mitigation Bank



Phase I

- 0.81 Ha wetland
- Adjacent stream: Goose Creek

Phase II

- 3.5 Ha
- Adjacent stream: Sycolin Creek

Phase III

- 3.9 Ha
- Adjacent stream: Beaverdam Creek

Methods

- 1,596 trees of 7 spp. and 3 stock types
- Planted in spring of 2009.
- There were 24 plots each with three or four 21-tree subplots.
  - Subplots (76) consisted of 7x3 tree arrays
    - (to represent the 7 species and 3 stock types).
- Morphometric data were gathered after planting and relative growth rates were calculated.
  - Height
  - Basal Diameter
    - Stem volume (cone, based on height and basal area)
  - Canopy Diameter

Field Validation

of large-scale field experiment
(Clear/white cells met 10% annual growth (height) requirement)

Survival results not shown and
tell a different story (Walters and Reich, 1996).

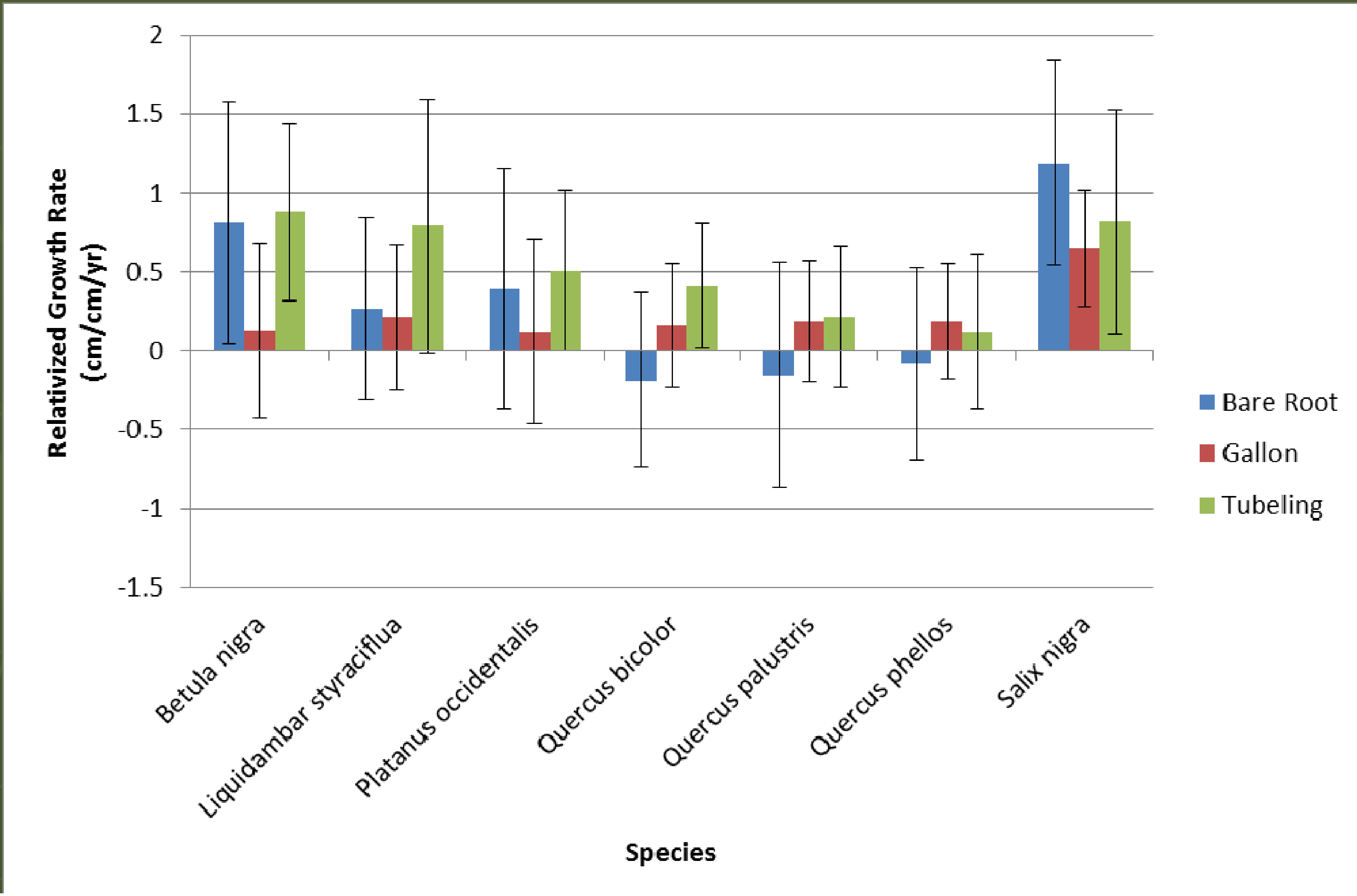
		Ideal				Saturated				Flooded				Field			
Species	Stocktype	2009 % Height	2010 % Height	2011 % Height	2012 % Height	2009 % Height	2010 % Height	2011 % Height	2012 % Height	2009 % Height	2010 % Height	2011 % Height	2012 % Height	2009 % Height	2010 % Height	2011 % Height	2012 % Height
Betula nigra	Bare root	112.2	173.9	132.9	49.4	12.2	84.3	126.1	60.7	28.8	62.5	-30.8	97.9	-9.5	35.4	24.7	43.8
Betula nigra	Gallon	523.0	85.7	60.4	46.8	652.9	34.3	61.7	87.1	33.4	5.1	17.0	-8.6	-4.0	-12.3	3.3	15.9
Betula nigra	Tubeling	83.9	130.4	144.3	62.9	102.7	105.3	122.5	59.5	16.7	13.6	-10.5	9.9	9.4	25.2	31.0	30.6
Liquidambar styraciflua	Bare root	108.1	164.3	104.5	46.7	-35.0	74.3	115.8	81.1	-8.8	5.6	-3.7	5.6	-5.9	-15.1	44.6	44.8
Liquidambar styraciflua	Gallon	402.1	87.8	70.9	39.3	226.9	58.1	58.9	57.7	42.2	-1.0	-4.5	1.8	5.5	-16.1	52.3	25.4
Liquidambar styraciflua	Tubeling	45.8	218.7	123.0	56.3	-103.3	99.3	143.6	56.4	36.9	20.2	3.2	19.6	22.7	75.8	46.4	35.2
Platanus occidentalis	Bare root	298.1	320.4	128.2	51.7	5.0	94.1	184.5	101.4	-57.5	-25.5	NA	NA	-24.1	26.7	37.6	38.7
Platanus occidentalis	Gallon	610.8	108.1	90.2	45.3	284.0	5.6	66.0	22.5	-45.5	-29.8	-22.3	-4.9	-13.6	-20.8	66.4	27.8
Platanus occidentalis	Tubeling NO SOIL	310.7	243.4	92.6	44.7	30.0	61.1	180.5	66.4	-53.1	10.2	0.0	-53.6	-19.0	5.9	47.5	46.4
Quercus bicolor	Bare root	103.0	17.0	45.8	42.4	133.7	16.7	55.2	38.1	2.1	-16.9	-36.9	20.5	2.5	-17.2	13.7	30.2
Quercus bicolor	Gallon	99.4	87.8	55.6	48.9	5.7	32.0	69.1	28.3	23.1	-3.2	-3.1	-2.8	10.5	6.5	19.1	17.6
Quercus bicolor	Tubeling	-93.5	33.0	76.7	68.2	-129.4	11.8	81.4	45.5	-7.7	-11.0	-15.9	15.0	4.2	54.9	37.5	24.6
Quercus palustris	Bare root	83.9	39.1	64.5	64.9	-84.9	13.8	95.0	47.8	-10.0	-30.9	-5.3	11.0	-1.2	-13.3	36.3	38.8
Quercus palustris	Gallon	295.4	22.8	37.9	47.8	254.2	3.9	33.2	27.6	3.9	-8.2	-44.7	3.5	3.6	11.8	1.2	26.6
Quercus palustris	Tubeling	-102.5	73.6	93.4	45.1	-129.3	56.1	70.5	78.2	-9.4	5.2	-12.9	8.0	-25.7	73.9	53.3	24.1
Quercus phellos	Bare root	10.1	32.8	73.6	69.7	-26.4	48.2	91.8	58.8	-25.0	-24.9	-4.7	67.2	-15.7	-39.3	30.2	33.8
Quercus phellos	Gallon	535.6	41.4	40.7	32.6	480.9	7.7	32.9	25.8	2.0	22.0	-15.2	-16.1	11.6	4.8	29.6	10.6
Quercus phellos	Tubeling NO SOIL	16.6	99.1	57.4	73.1	-63.8	67.4	81.5	59.7	-68.7	-39.2	NA	NA	-31.8	-55.6	117.0	37.4
Salix nigra	Bare root	-56.9	137.4	80.3	104.2	41.0	155.3	135.7	73.1	41.0	72.7	21.4	25.5	0.7	60.8	37.0	34.3
Salix nigra	Gallon	518.5	22.6	48.1	43.6	256.5	0.3	89.0	45.6	17.3	1.5	-3.7	2.8	7.1	2.4	21.0	29.2
Salix nigra	Tubeling NO SOIL	197.8	101.2	125.0	62.1	-3.2	34.8	112.1	77.3	22.3	62.8	38.3	5.8	0.6	21.9	27.1	37.8

Soil analysis for modeling growth

Response Variable: Relative Growth Rate

Year 3 because we sampled soils that year.

Stem volume selected as a combination of height and basal area.



Soil Methods

- A soil pit was dug in the middle row.
- Samples were collected
  - By combining two 51-mL soil tins
  - Obtained at two depth increments: 0-12 and 12-24 cm.
- Most soil analyses were performed at USGS headquarters in Reston, VA.

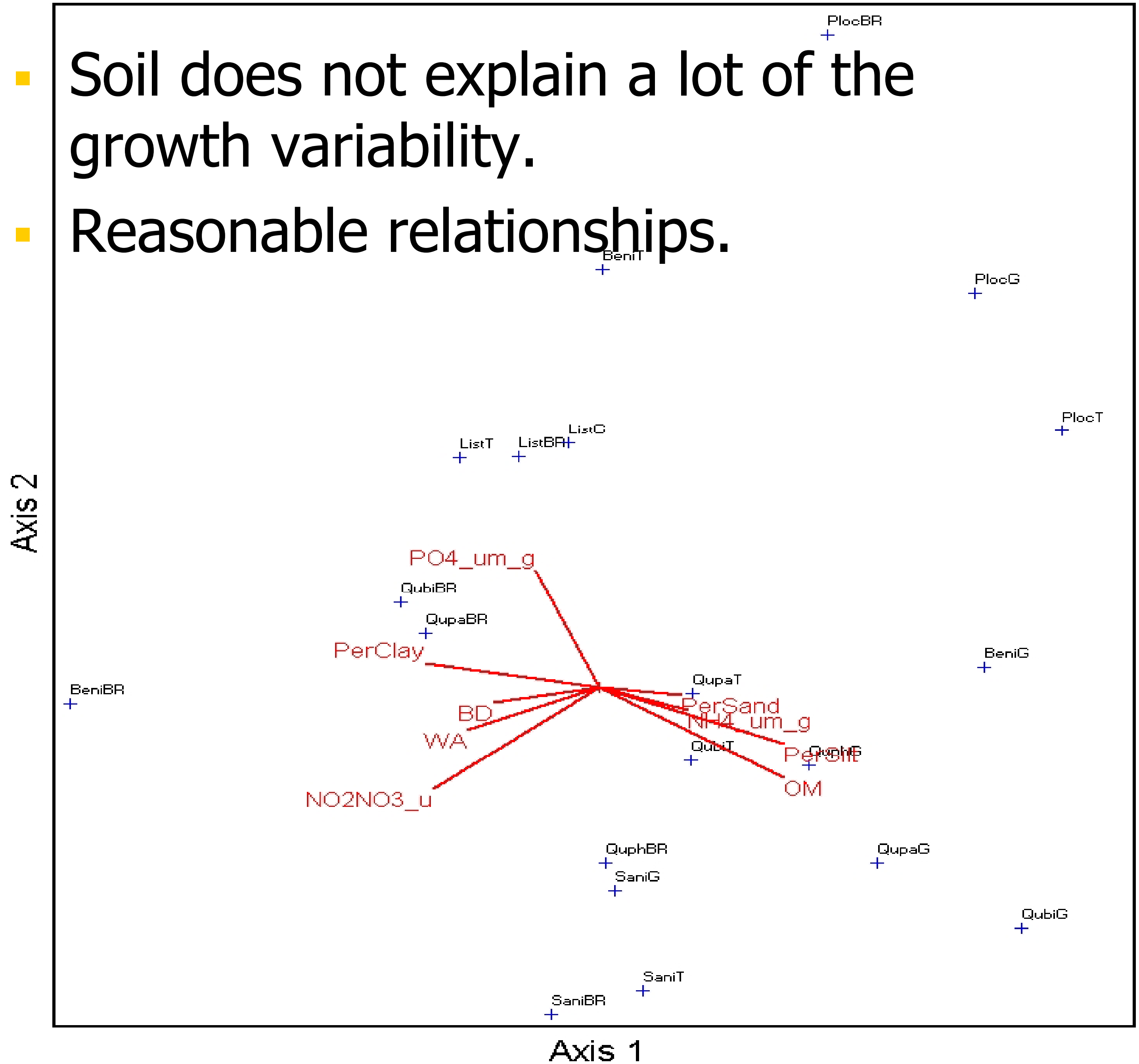
Soil Parameters

- Soil Physical
  - Bulk Density (BD)
  - Organic Matter Content
  - Particle Size (Percent Clay, Silt, Sand)
- Soil Chemical
  - Nitrate/Nitrite (KCl extractable)
  - Ammonium (KCl extractable)
  - Phosphate (Mehlich extractable)
- Hydrologic
  - Weighted Average (WA, based on vegetation)
  - Average Water Level and Elevation
- Vegetative
  - Shade Score (vertical cover board)

Canonical Correspondence Analysis (CCA)
(PC-ord v. 5.10, 2006)

- Used to determine association between species responses and environmental parameters.
- *Quercus phellos* Tubeling not included due to high mortality (92%).

- Soil does not explain a lot of the growth variability.
- Reasonable relationships.



Results: Forward Stepwise

- Environmental parameters used to predict relative growth via FSR (SigmaPlot v. 12).
- Standardized coefficients and R^2 when significant relationship found.
- Only 6 out of 20 had significant relationships, esp.
  - *P. occidentalis* (Bare Roots)
  - *S. nigra* (Tubelings)

Species	WA	BD	NO3	NH4	PO4	OM	PerClay	PerSand	PerSilt	WtrLvl	R^2
Beni G	*	*	*	*	.28	*	*	.4	*	*	0.165
Ploc BR	*	-.62	*	-.39	*	*	*	*	*	*	0.363
Ploc G	.45	*	*	*	*	*	*	*	*	*	0.200
Ploc T	*	*	*	*	*	.39	*	*	*	*	0.152
Quph BR	*	-.46	*	*	*	*	*	*	*	*	0.212
Sani T	.46	.39	*	.65	*	*	*	*	*	*	0.363

AIC Modeling

an information criterion value developed by Dr. Akaike

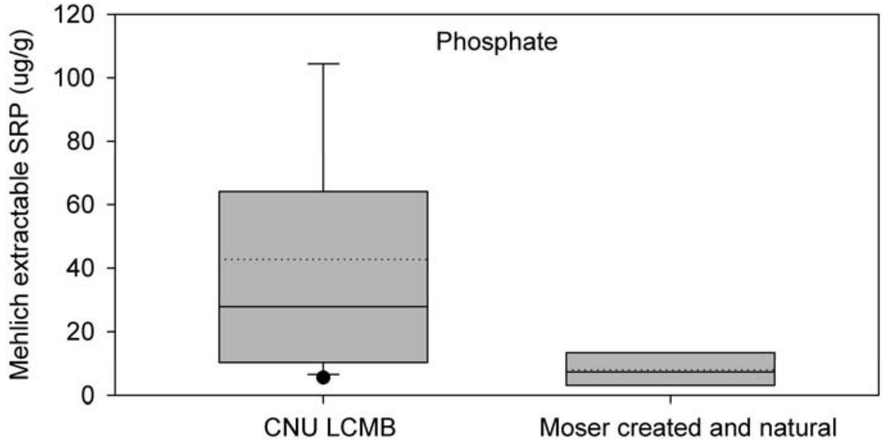
- Every combination of parameters was analyzed individually to explain growth per species based on AIC (SAS software).
- The parameter coefficients were then averaged to develop the best models (R software).
- Stock type included as a parameter in these models.

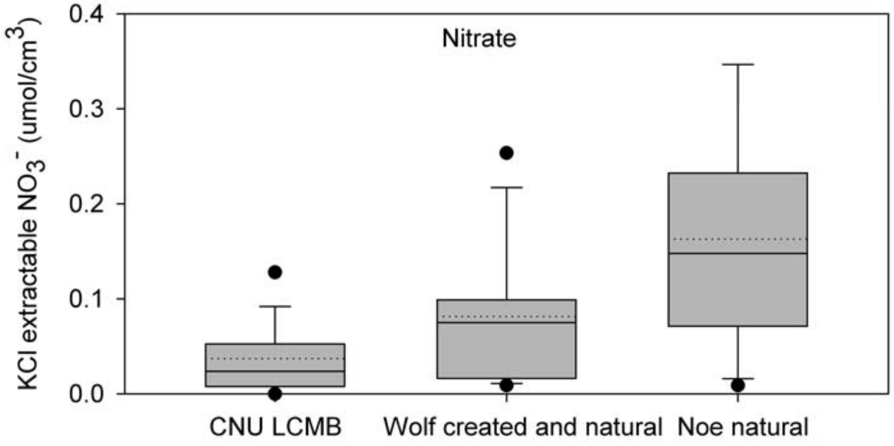
Results: AIC

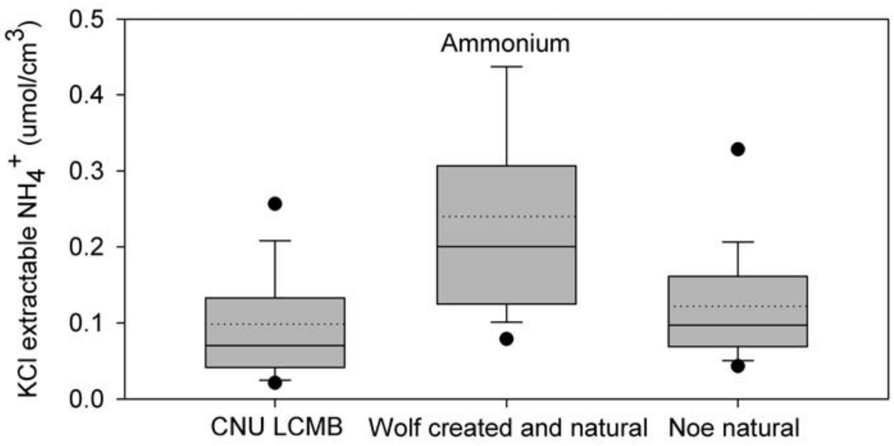
Parameter	Range	Mean	Importance (via AIC)
Bulk Density	0.76 – 1.28g/cm^3	1.03 ± 0.12g/cm^3	List
Organic Matter Content	4.36 – 7.69%	5.21 ± 0.59%	List*, Ploc, Qubi, Qupa, Quph*
Percent Clay	12.4 – 35.36%	25.6 ± 5.44%	
Percent Silt	62.9 – 77.35%	67.5 ± 3%	
Percent Sand	0.21 – 23.83%	6.89 ± 4.85%	
Nitrate/Nitrite Conc.	0.002 – 0.15µmol/cm^3	0.04 ± 0.04µmol/cm^3	List, Ploc*, Qubi, Quph
Ammonium	0.02 – 0.51µmol/cm^3	0.1 ± 0.08µmol/cm^3	
Phosphate	0.12 – 4.63µmol/cm^3	1.37 ± 1.32µmol/cm^3	
Weighted Average	1.12 – 2.68	1.81 ± 0.34	
Average Water Level	-3.37 – 1.1m	0.18 ± 0.24	
Stock Type	1, 2, 3	N/A	Beni*, Qubi*, Qupa*, Sani*

- Importance defined as low AIC ($\Delta i < 2$; * = lowest AIC).
- 5 of 7 species affected by organic matter and/or N.

Our P and N vs literature values, showing N is a little low







What else could be limiting growth?

Other Parameters

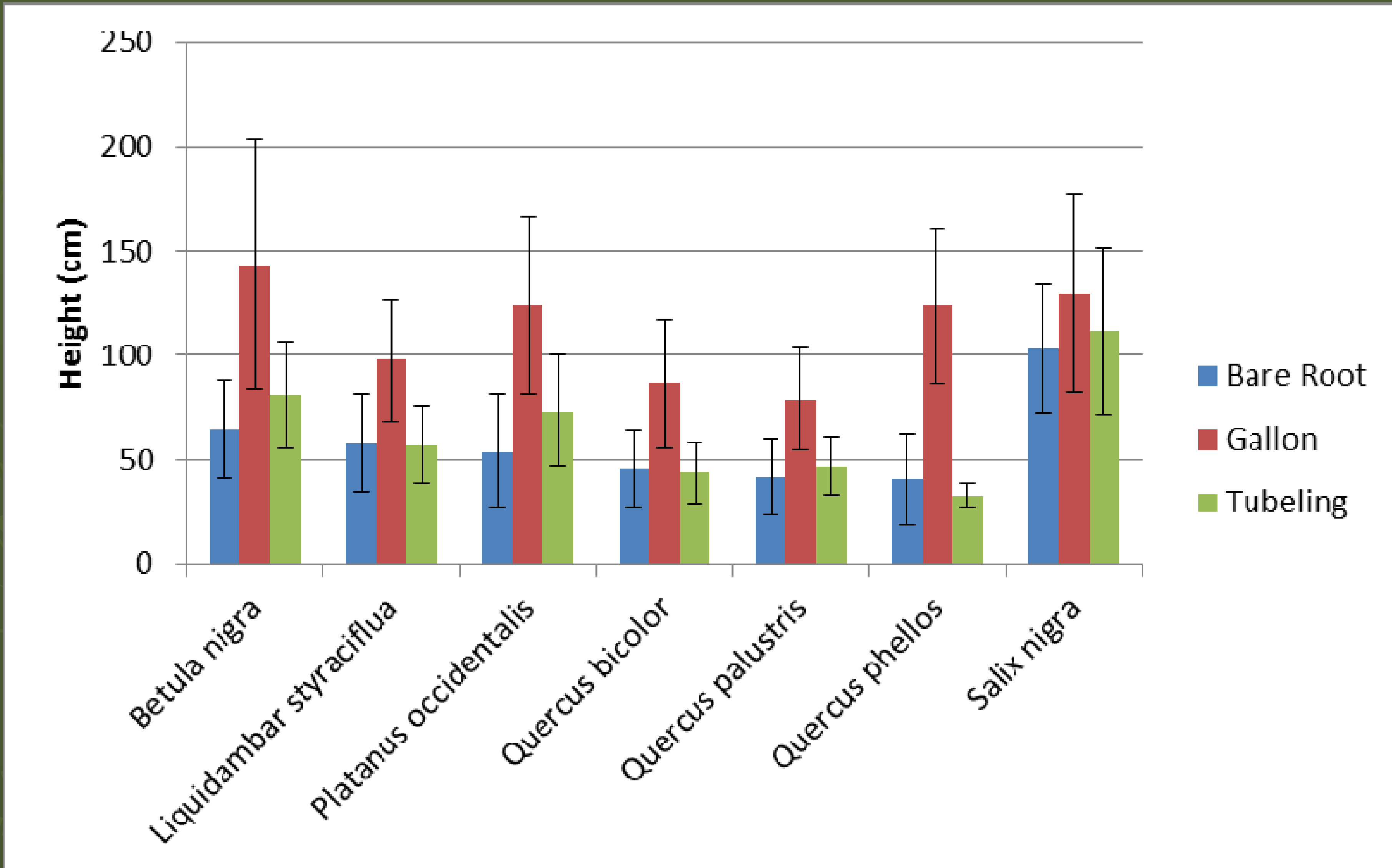
Hydrology

WA was a moderately effective surrogate.

Elevation measured at every tree was not related to growth, possibly due to microtopography.

Vegetation…

Year Three: Height
Note: NOT relative growth rate



Shade/Competition

Based on height difference, this *Salix nigra* was 100 cm tall and the adjacent vegetation was 0.75 m tall (as measured with a vertical cover board). The difference (+0.25) was inserted into the model.

Results: Model averaging without and with shade

Final averaged models: Without Shade

Species	Intercept	Plant Cat	WA	BD	NO3	NH4	PO4	OM	PerClay	R^2
BENI	1.147	-0.371	0.303	0.741	-3.468	-1.093	0.070	-1.237	-0.019	0.229
LIST	0.692	-0.035	0.288	-0.840	-0.142	0.339	0.116	-3.089	-0.015	0.048
PLOC	0.023	-0.15	0.464	-0.487	-4.3	-0.586	0.066	3.597	0.011	0.095
QUBI	-0.085	0.138	0.099	-0.327	-0.795	-0.042	-0.013	1.296	-0.006	0.059
QUPA	-0.254	0.157	-0.024	-0.080	0.143	-0.189	-0.008	1.186	0.003	0.059
QUPH	0.263	0.129	-0.053	-0.978	-2.168	-0.184	0.037	4.936	0.012	0.139
SANI	-1.348	-0.258	0.497	1.370	-3.672	1.885	-0.039	4.253	0.004	0.231

Final averaged models: With Shade

Species	Intercept	PlantCat	WA	BD	NO3	NH4	PO4	OM	PerClay	VegH	R^2
BENI	1.49	-.508	.256	.675	-2.54	-.981	.023	-2.11	-.014	.004	.314
LIST	.661	-.097	.253	-.615	-.225	.376	.101	-1.94	-.011	.003	.111
PLOC	1.31	-.399	.182	-.522	-3.25	-.971	.08	4.37	.002	.007	.383
QUBI	.335	.056	.13	-.309	-.82	-.094	-.022	.334	-.004	.003	.110
QUPA	-.159	.147	-.014	-.083	.125	-.266	-.007	.87	.005	.001	.102
QUPH	.10	-.028	-.006	-.698	-1.35	.203	.02	4.9	.013	.003	.300
SANI	-.324	-.329	.361	.973	-2.4	1.14	-.006	3.89	.01	.005	.359

Discussion

- Growth requirements were met regardless of soil condition.
- Each tree responded to parameters in slightly different ways. While statistical significance is low, AIC suggested
  - Initial Stock Type:
    - Best performers: Be ni (Bare Root/Tubeling), Qu bi (Tubeling), Qu pa (Gallon), Sa ni (Bare Root).
    - Performance based on stock types may become less important as trees age.
  - Organic Matter:
    - Qu ph (positive).
  - Nitrate/Nitrite Concentration:
    - Pl oc (negative).

Discussion

- Though confidence in these models are low due to low R^2 values, the best models were provided by AIC:
  - *Platanus occidentalis* (better with less competition, lower nutrients, and higher organic matter)
  - *Salix nigra* (better with less competition, higher bulk density, planted as a bare root)

Discussion

- N and P were both limiting in 20-yr old created wetlands (Atkinson et al. 2010), but those were somewhat isolated hydrologically.
- Nitrogen is associated with organic matter which can be derived from autochthonous and allochthonous sources associated with overbank flooding.
  - Watershed considerations such as stream adjacency were recommended by the USCOE and USEPA (2008 Final Rule), and other ecosystem services are enhanced by adjacent stream connections to wetlands.

Conclusion

- Tree growth is adequate by year 3 for most species and stock types.
- Soils are unlikely to be acting as drivers of tree growth in our sites.
- Competition or other relationships with colonizing herbaceous species may affect or predict success.

Acknowledgements

- Peterson Family Foundation *(7-year studies are rare)*
- Wetland Studies and Solutions, Inc.
- Jim Perry and Wes Hudson of VIMS
- Jon Lefcheck of VIMS
- Dept. of Organismal and Environmental Bio. at CNU

Peterson Family Foundation

Christopher Newport University

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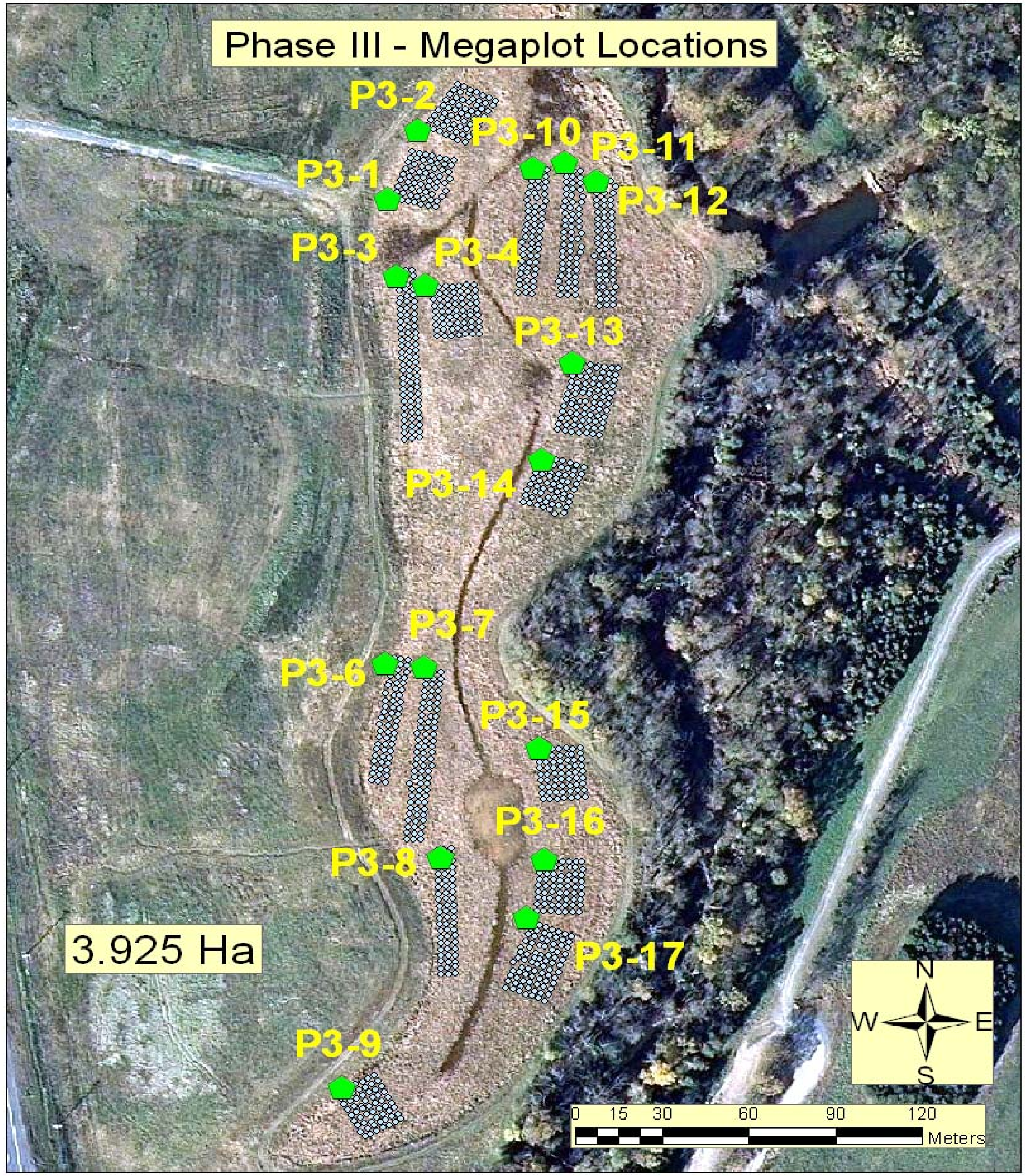
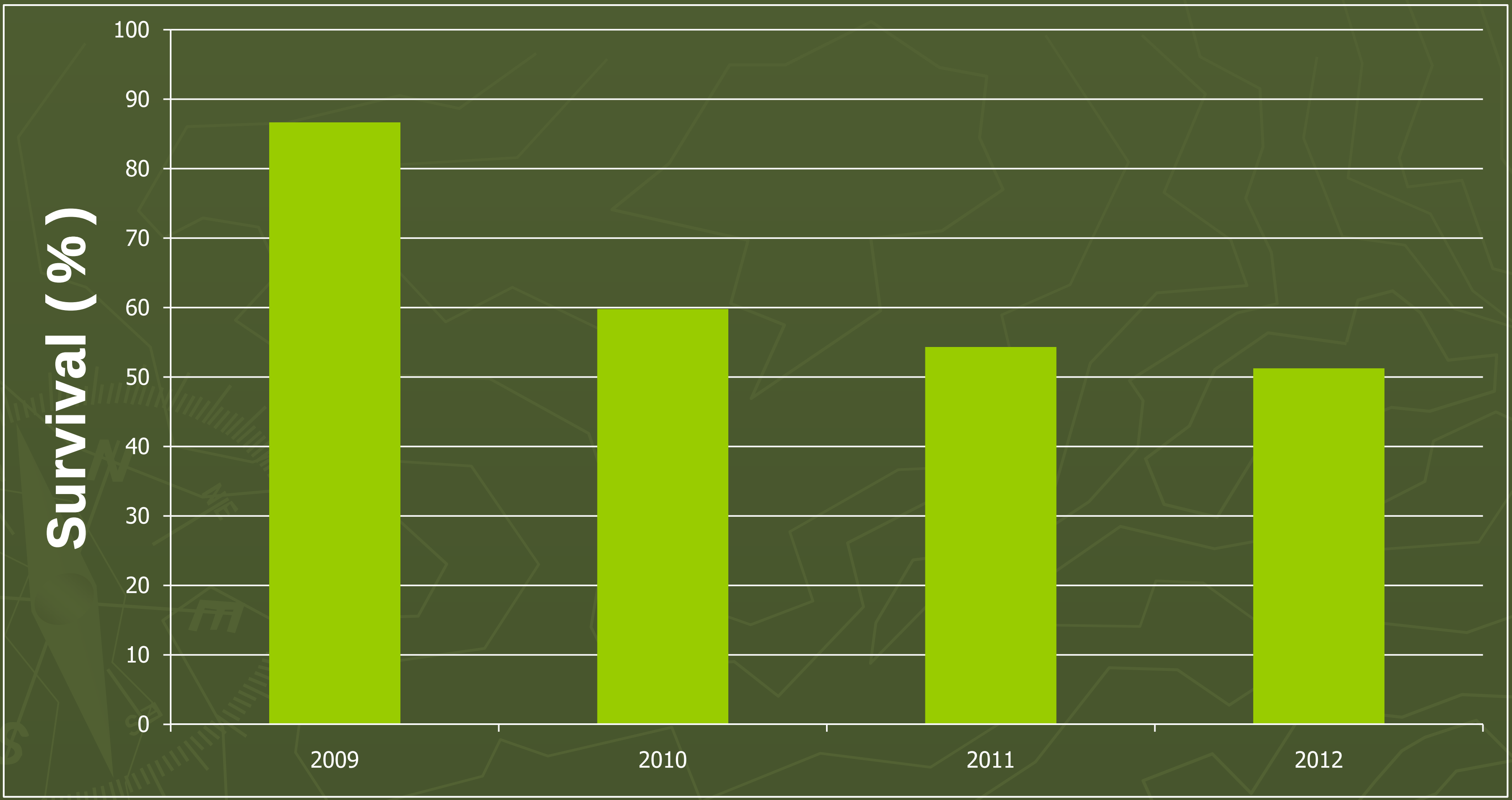
Thank You!


Thank You!
Goose Creek near Phase I


Phase III - Megaplot Locations
P3-2
P3-10
P3-11
P3-1
P3-12
P3-3
P3-4
P3-13
P3-14
P3-7
P3-6
P3-15
P3-16
P3-8
3.925 Ha
P3-17
P3-9
N
W
E
S
0 15 30 60 90 120
Meters

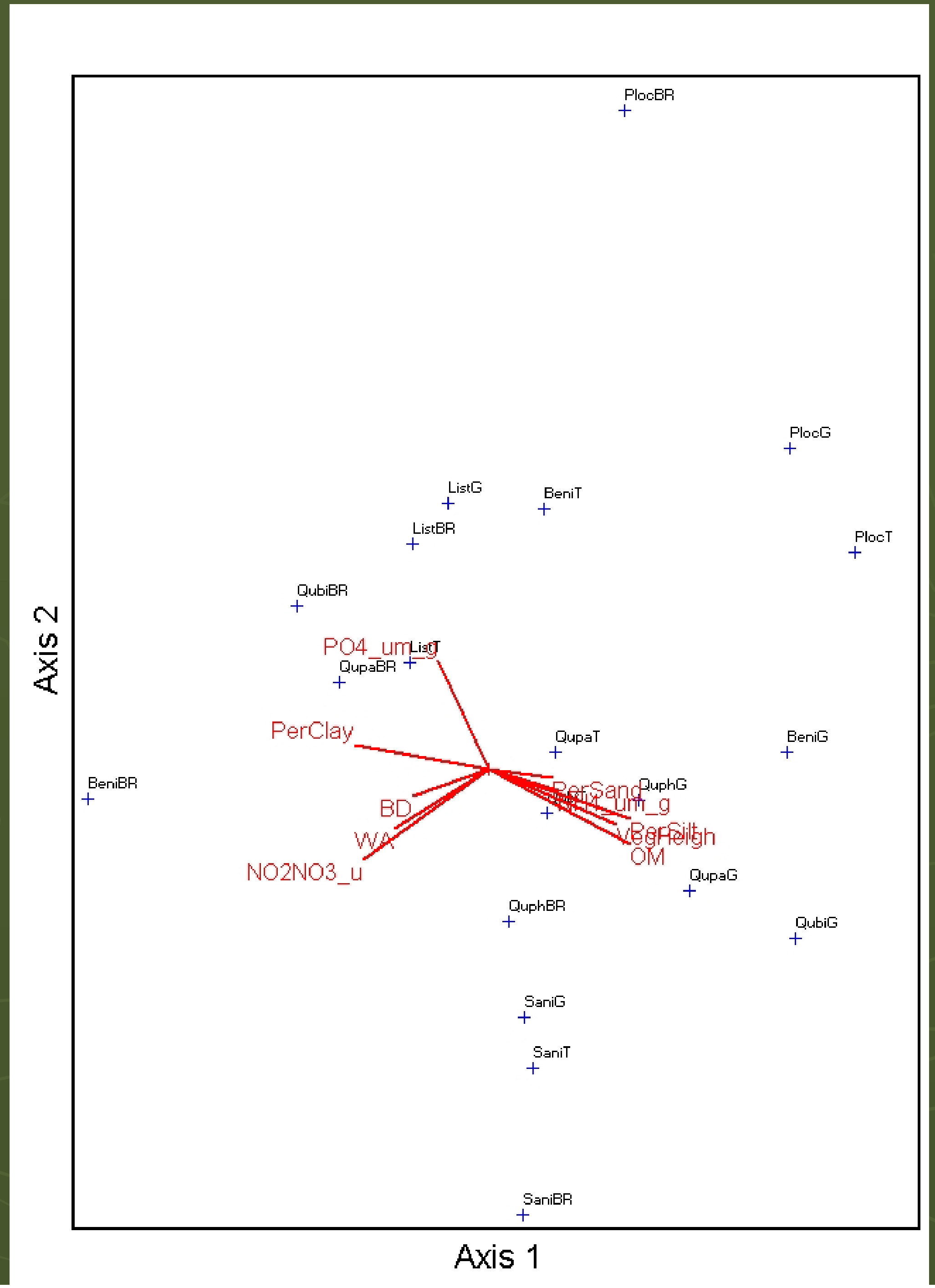
Summary of Survival (cumulative)
Survival rates improved by the third growing season



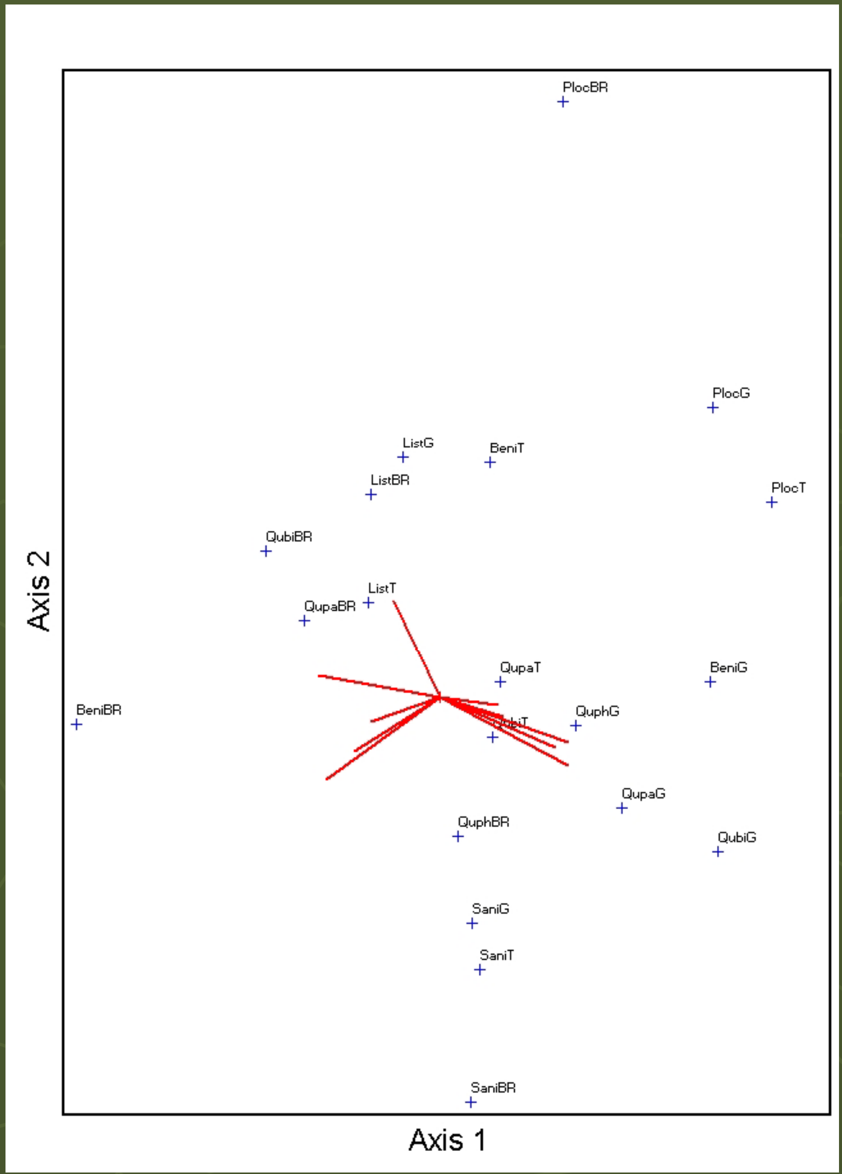
Final Models W/ Competition

- Final averaged models including a parameter quantifying the height of the trees relative to surrounding vegetation (VegH).

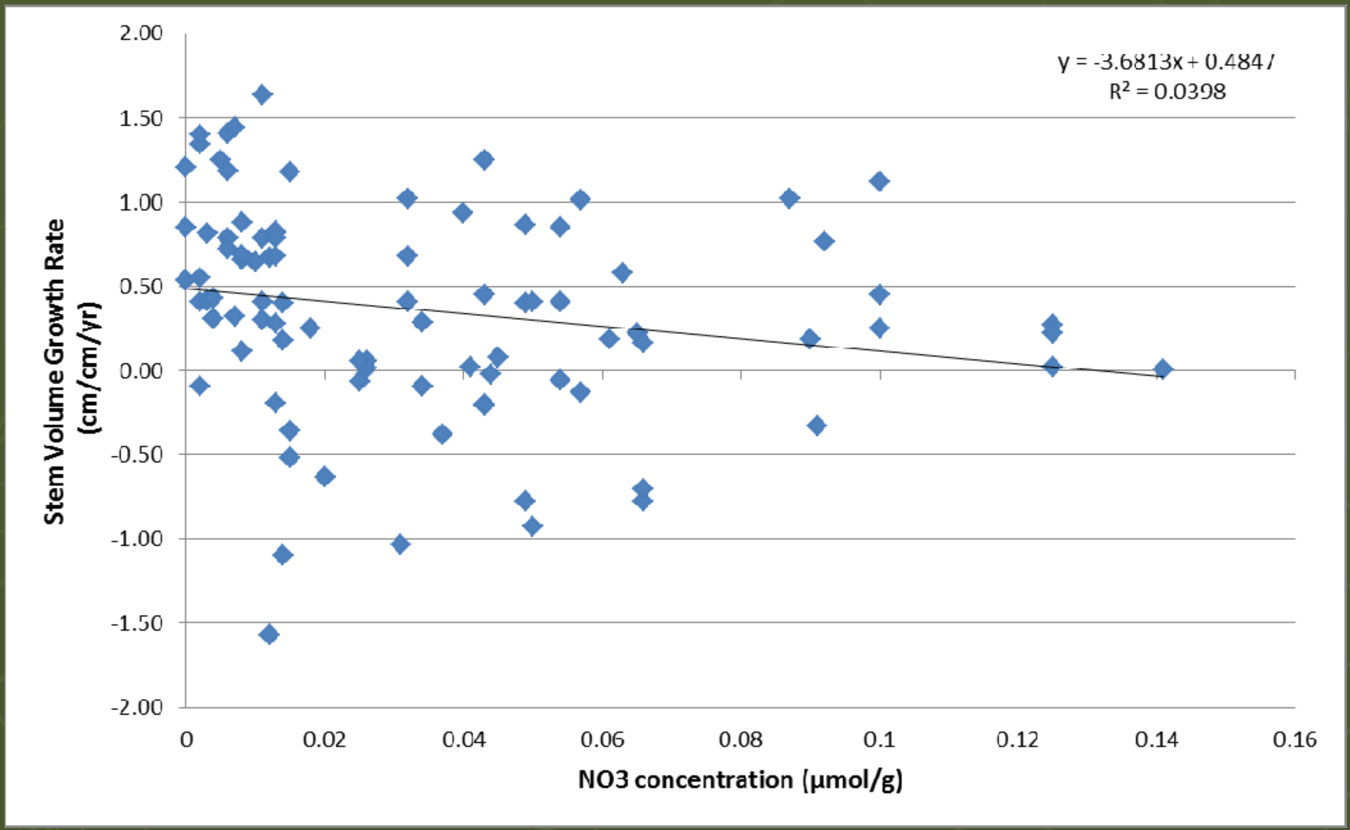
- Axis 1:
  - 5.3%
- Axis 1,2,3:
  - 11.9%

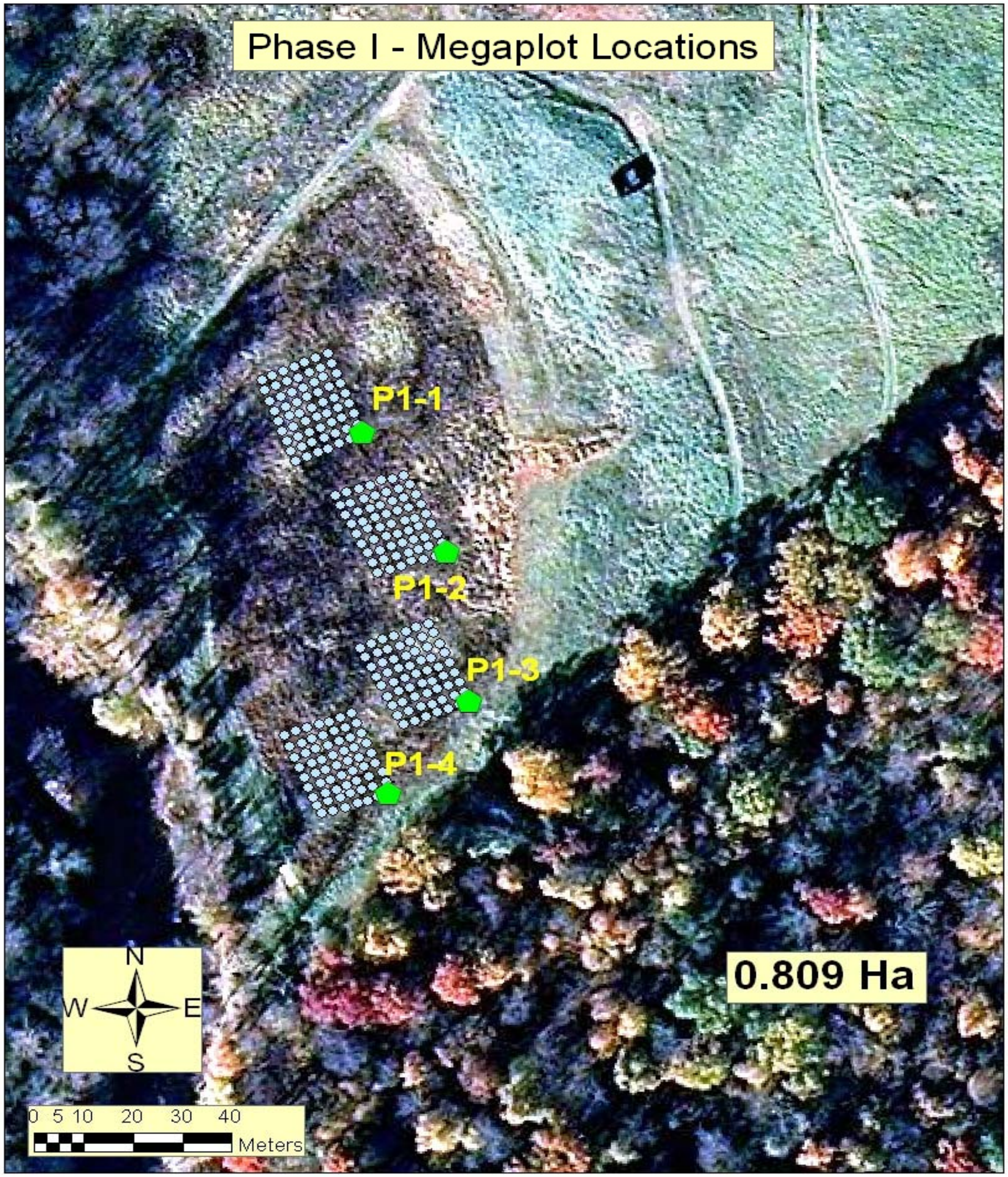


- Axis 1:
  - 5.3%
- Axis 1,2,3:
  - 11.9%



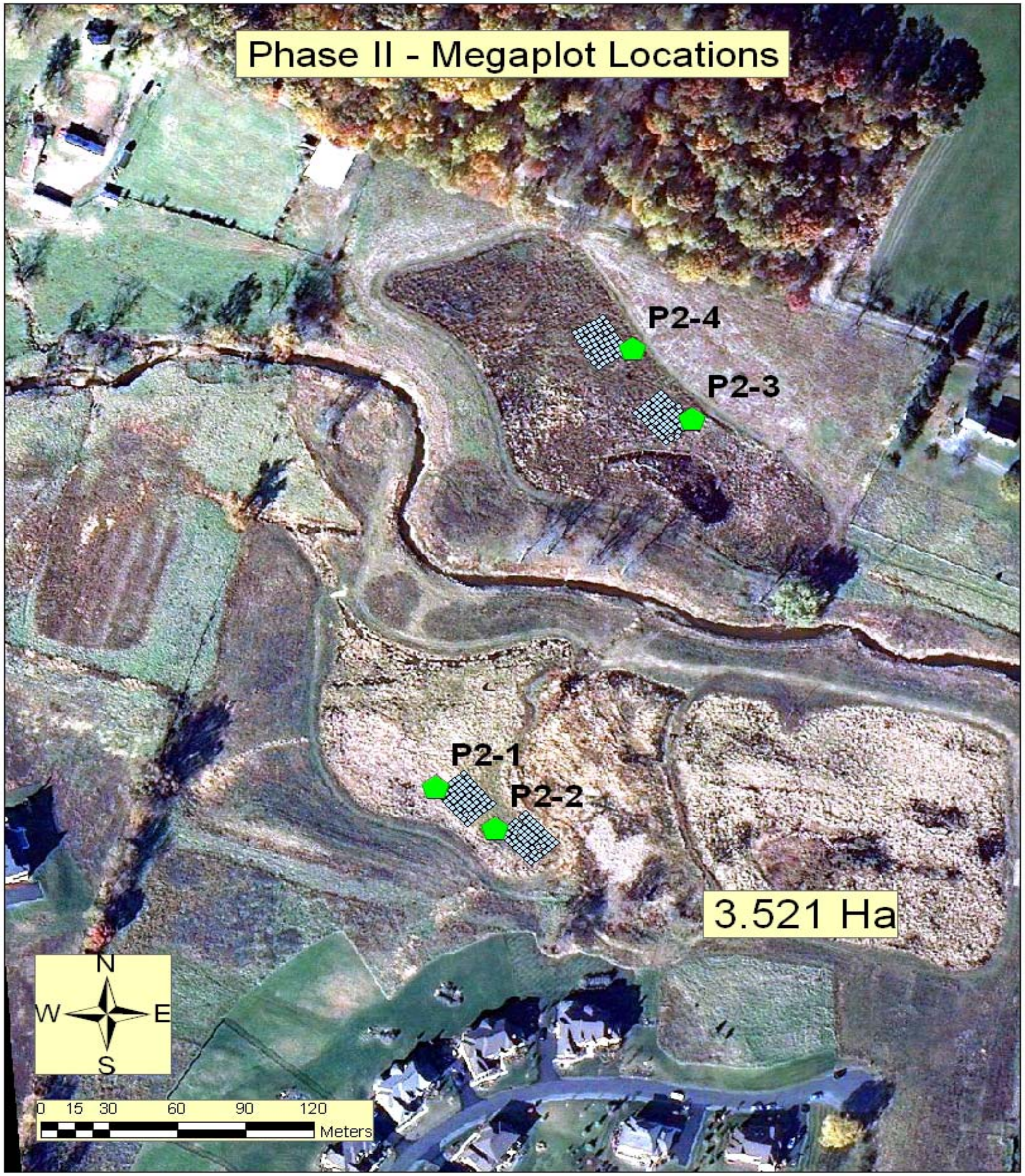
Nitrate effect on Growth




Phase I - Megaplot Locations
P1-1
P1-2
P1-3
P1-4
N
W
E
S
0 5 10 20 30 40
Meters
0.809 Ha

Conclusions

- The final averaged model for each species could be used as an equation to estimate the amount of growth the tree could achieve with given environmental conditions.
- Different tree species will do better in certain environmental conditions and with certain pre planting considerations
  - Soil amendments.
  - Stock type considerations.



Phase II - Megaplot Locations
P2-4
P2-3
P2-1
P2-2
3.521 Ha
N
W
E
S
0 15 30 60 90 120
Meters

Soil: Bulk Density Analysis

- Samples were homogenized while wet and then 50 grams were weighed out and dried at 60°C for 24 hours.
- Using the amount of sample lost during drying (soil moisture) and the initial "wet" weight we determined the bulk density.
- Dried sample filtered through 1-mm sieve to prepare for nutrient analysis.

Soil: SFA

- Segmented Flow Auto-Analyzer.
- KCl Extraction (Nitrogen)
  - 4g “wet” weight equivalent added to 40mL KCl solution.
  - Shaken for 1 hour and centrifuged for 5 minutes then filtered; processed in the SFA.
- Mehlich-3 Extraction (Phosphorus)
  - 2g “wet” weight equivalent added to 20 mL Mehlich-3 solution.
  - Shaken for 5 minutes then filtered; processed in the SFA.

Soil: LISST-100X Analysis

- Laser In-Situ Scattering and Transmissometry (LISST) analyzer is used to determine sizes of particles present in a solution.
- 3g of dried sample combusted at 550°C then filtered by a 250-µm sieve.
- 0.02 grams of the sample were added to a solution of 10mL Hexametaphosphate and 90mL DI-water; then shaken for 16 hours.
- These mixed samples were then processed in the LISST.

Hydrology Methods

- Herbaceous cover estimates and weighted averages were calculated using 1-m^2 plots in the summer of 2011.
  - Shade estimated using vertical cover board consisting of four 0.5-m sections at each tree.
- Water level data was obtained from WSSI via hand-read wells at each phase.

Information Testing

- Develop the best models given only the collected parameters.
- Uses an information criterion value (i.e. AIC) to quantify information loss.
- Lower AIC values means that the model has the least information lost.
- The strength of additional models is determined by the difference in their AIC (Δi).

Discussion

- In this study, P was similar to other created wetlands and was not limiting according to most of our models.
- N-limitations have been noted for young sites but increased with site age (Wolf, Ahn and Noe 2011).
-

Discussion

- Trees in this field validation study grew most similarly to the wettest treatment in our large scale field treatment.
  - A silviculture practice that would allow these seemingly mutually-exclusive design elements is bedding or mounding.
    - Is typically used by WSSI but was not included in this study.